

## Measurements of the Vertical Structure of Aerosols and Clouds Over the Ocean Using Micro-pulse LIDAR Systems

Ellsworth J. Welton

Goddard Earth Sciences and Technology Center, University of Maryland Baltimore County, Greenbelt, MD, 20771.

James D. Spinhirne

NASA Goddard Space Flight Center, Greenbelt, MD, 20771.

James R. Campbell

Science Systems and Applications, Inc., Lanham, MD, 20706.

Timothy A. Berkoff

Goddard Earth Sciences and Technology Center, University of Maryland Baltimore County, Greenbelt, MD, 20771.

David Bates

Physics Department, University of Miami, Coral Gables, FL, 33146.

*Submission to the SIMBIOS Project 2001 Annual Report, a NASA Technical Memorandum*

### INTRODUCTION

The determination of the vertical distribution of aerosols and clouds over the ocean is needed for accurate retrievals of ocean color from satellites observations. The presence of absorbing aerosol layers, especially at altitudes above the boundary layer, has been shown to influence the calculation of ocean color [Gordon *et al.*, 1997a]. Also, satellite data must be correctly screened for the presence of clouds, particularly cirrus, in order to measure ocean color [Gordon *et al.*, 1997b].

One instrument capable of providing this information is a lidar, which uses pulses of laser light to profile the vertical distribution of aerosol and cloud layers in the atmosphere. However, lidar systems prior to the 1990s were large, expensive, and not eye-safe which made them unsuitable for cruise deployments. During the 1990s the first small, autonomous, and eye-safe lidar system became available: the micro-pulse lidar, or MPL [Spinhirne *et al.*, 1995]. The MPL is a compact and eye-safe lidar system capable of determining the range of aerosols and clouds by firing a short pulse of laser light (523 nm) and measuring the time-of-flight from pulse transmission to reception of a returned signal. The returned signal is a function of time, converted into range using the speed of light, and is proportional to the amount of light backscattered by atmospheric molecules (Rayleigh scattering), aerosols, and clouds. The MPL achieves ANSI eye-safe standards by sending laser pulses at low energy ( $\mu\text{J}$ ) and expanding the beam to 20.32 cm in diameter. A fast pulse-repetition-frequency (2500 Hz) is used to achieve a good signal-to-noise, despite the low output energy. The MPL has a small field-of-view ( $\leq 100 \mu\text{rad}$ ) and signals received with the instrument do not contain multiple scattering effects. The MPL has been used successfully at a number of long-term sites and also in several field experiments around the world [Welton *et al.*, 2000; Peppler *et al.*, 2000; Voss *et al.*, 2001; Welton *et al.*, 2001a].

In 1999, members of the Micro-pulse Lidar group at GSFC submitted a proposal to organize a worldwide network of MPL systems to provide long-term measurements of the vertical distribution of clouds and aerosols at sites around the world. The original proposal also included support for a limited number of field experiments each year. In the summer of 2000, NASA EOS agreed to fund the proposal, and the MPL-Net project [Welton *et al.*, 2001b] was started. The CERES validation group at NASA LaRC contributed four MPL systems to MPL-Net, supplementing the existing stock of instruments. Finally, in the fall of 2000 the NASA SIMBIOS program agreed to fund another proposal to conduct lidar measurements from research vessels at sea using the SIMBIOS MPL system. This effort provides the SIMBIOS project with continuous observations of aerosol and cloud vertical distributions during up to two cruises per year.

## RESEARCH ACTIVITIES

### *ACE-Asia Cruise*

The third Aerosol Characterization Experiment (ACE) was conducted in Asia during March and April 2001. The experiment, referred to as ACE-Asia, utilized inland and island ground stations, aircraft, and ship platforms to study dust and pollution aerosols over Asia and the surrounding region. The Asian derived aerosols are important to satellite based ocean color measurements because the dust and pollution plumes transport far over the North Pacific Ocean. Dust absorbs sunlight in the visible wavelengths, and its vertical distribution over the ocean can affect the retrieval of ocean color.

The SIMBIOS MPL was deployed onboard the NOAA ship R/V Ronald H. Brown during ACE-Asia in order to determine the height of Asian aerosol plumes over the ocean. The MPL was operated from March 22 to April 20, 2001. Figure 1 shows the cruise track during ACE-Asia. Measurements were not continuous because of temperature stability problems in MPL van. The A/C unit on the van was damaged during a storm early in the cruise, and reliable temperature control was not possible for the remainder of the cruise. The MPL was operated only when the temperatures could be monitored manually, resulting in approximately 30% to 40% downtime over the whole cruise. The MPL ran continuously otherwise.

The MPL signals are stored at 1-minute time intervals, with a range resolution of 0.075 km from sea level up to a maximum altitude of 20 km. The raw data are converted into uncalibrated lidar signals, referred to as Normalized Relative Backscatter (NRB), using procedures discussed in *Campbell et al.* [2001] and *Welton and Campbell* [2001]. The NRB signals are then analyzed to produce profiles of aerosol extinction and optical depth, and the layer averaged extinction-to-backscatter ratio, using techniques discussed in the Appendix of *Welton et al.* [2001a].

### *MPL Instrument Development*

The original MPL design used a fixed-place detector that was part of the optical path within the instrument. If the detector failed, it could not be replaced without performing a complete re-alignment of the MPL. This is not possible at sea. As a result, the health of the detector determined whether or not a particular cruise was a failure or a success. In order to overcome this problem, the MPL system was modified to incorporate a fiber-coupled detector. The detector itself is the same, however, it is no longer part of the optical path. It is connected to the optical path by a fiber cable. The detector can now be replaced by simply unscrewing the old detector from the fiber, and replacing it with a new one. This can be accomplished at sea with a minimum of effort, and can be performed by anyone with a small amount of training.

## RESEARCH RESULTS

Figure 2 shows a plot of the NRB signals vs. day of year during the ACE-Asia cruise. The gaps in data, due to the problems discussed in the previous section, are shown in black. Regions of higher signal indicate the presence of aerosols and clouds. The period around day 100, April 10, is of interest because the ship was in the Sea of Japan and positioned downwind of a massive dust storm that occurred a few days earlier over China. Preliminary aerosol optical data products have been generated for this time period. Figure 3 shows profiles of the NRB signal, extinction, and optical depth on April 10 at 0500 UTC. The aerosols are confined to two distinct layers. The lower layer extends from 0 to 2 km, and the upper from about 3.5 to 5.5 km. Cirrus is also present from 10 to 14 km, but is not included in the extinction retrieval because it is a cloud.

The aerosol extinction-to-backscatter ratio,  $S$ , for the lower and upper layers was 32 and 66 sr, respectively.  $S$  is proportional to the aerosol phase function at  $180^\circ$  and inversely proportional to the aerosol single scattering albedo. Layers with a high value of  $S$  tend to have a lower single scattering albedo, and therefore more aerosol absorption relative to layers with a lower value of  $S$ . The preliminary results shown here indicate that the upper aerosol layer was more absorbing than the lower layer. Therefore, the aerosols observed on this day may have influenced the retrieval of ocean color in this region.

This observation also serves as an example of the MPL's ability to distinguish aerosol layers from clouds. The microtops sunphotometer on the ship measured optical depths over 1 at 500 nm, at least 0.8 larger than the aerosol optical depth from the MPL. However, the NRB signal shows that a cirrus cloud was present during this time. The cirrus cloud optical depth was approximately 0.8 based on the difference between the microtops and MPL results.

## DISCUSSION/FUTURE PLANS

The results from the ACE-Asia cruise are still being analyzed. The NRB data has been fully processed and files are available on the SEABASS archive and also on the MPL-Net web-site (<http://virl.gsfc.nasa.gov/mpl-net/>). The remaining data products will be available only on the MPL-Net web-site. Some of these data are available now for the purpose of preparing papers, however the data are not quality assured. Final, quality assured extinction and optical depth data from ACE-Asia will be available by spring 2002 at the latest.

The results from the ACE-Asia cruise will be used together with other MPL-Net measurements made during the experiment to assess whether or not aerosol transport models predict the correct vertical distribution. This work will become the focus of a paper over the course of the next several months. In addition, numerous publications, as co-authors, are planned with other researchers involved in ACE-Asia studies.

The MPL will be readied for the next series of deployments during 2002. A cruise is planned in the North Atlantic Ocean during the spring. This cruise will be aimed at studying the vertical distribution of Saharan dust over the ocean. Finally, the MPL will also be made available for a cruise scheduled in the summer. Our group will not participate directly in the cruise, but will help support the MPL measurements and analysis.

## REFERENCES

- Campbell, J.R., D.L. Hlavka, E.J. Welton, C.J. Flynn, D.D. Turner, J.D. Spinhirne, V.S. Scott, and I.H. Hwang. 2001: Full-time, Eye-Safe Cloud and Aerosol Lidar Observation at Atmospheric Radiation Measurement Program Sites: Instrument and Data Processing, *J. Atmos. Oceanic Technol.*, in press.
- Gordon, H. R., T. Du, and T. Zhang. 1997a: Remote sensing of ocean color and aerosol properties: resolving the issue of aerosol absorption, *Appl. Optics*, **36**, 8670-8684.
- Gordon, H. R., T. Zhang, F. He, and K. Ding. 1997b: Effects of stratospheric aerosols and thin cirrus clouds on atmospheric correction of ocean color imagery: Simulations, *Appl. Optics*, **36**, 682-697.
- Peppler, R.A., C.P. Bahrmann, J.C. Barnard, J.R. Campbell, M.D. Cheng, R.A. Ferrare, R.N. Halthore, L.A. Heilman, D.L. Hlavka, N.S. Laulainen, C.J. Lin, J.A. Ogren, M.R. Poellot, L.A. Remer, K. Sassen, J.D. Spinhirne, M. E. Splitt, and D.D. Turner. 2000: ARM Southern Great Plains Site Observations of the Smoke Pall Associated with the 1998 Central American Fires, *Bull. Amer. Meteor. Soc.*, **81**, 2563-2591.
- Spinhirne, J. D., Rall, J., and V. S. Scott. 1995: Compact eye-safe lidar systems. *Rev. Laser Eng.*, **23**, 26-32.
- Voss, K.J., E.J. Welton, P.K. Quinn, J. Johnson, A. Thompson, and H. Gordon. 2001: Lidar Measurements During Aerosols99, *J. Geophys. Res.*, **106**, 20821-20832.
- Welton, E.J., K.J. Voss, H.R. Gordon, H. Maring, A. Smirnov, B. Holben, B. Schmid, J.M. Livingston, P.B. Russell, P.A. Durkee, P. Formenti, M.O. Andreae. 2000: Ground-based Lidar Measurements of Aerosols During ACE-2: Instrument Description, Results, and Comparisons with other Ground-based and Airborne Measurements, *Tellus*, **B52**, 635-650.
- Welton, E.J., K.J. Voss, P.K. Quinn, P.J. Flatau, K. Markowicz, J.R. Campbell, J.D. Spinhirne, H.R. Gordon, and J.E. Johnson. 2001a: Measurements of aerosol vertical profiles and optical properties during INDOEX 1999 using micro-pulse lidars, *J. Geophys. Res.*, in press.
- Welton, E.J., J.R. Campbell, T.A. Berkoff, J.D. Spinhirne, S. Tsay, and B. Holben. 2001b: First Annual Report: The Micro-pulse Lidar Worldwide Observational Network, *Project Report*, <http://virl.gsfc.nasa.gov/mpl-net/>.
- Welton, E.J., and J.R. Campbell. 2001: Micro-pulse Lidar Signals: Uncertainty Analysis, *J. Atmos. Oceanic Technol.*, submitted.

## FIGURE CAPTIONS

Figure 1. The cruise track of the R/V Ronald H. Brown during ACE-Asia is shown from days 75 to 92 (left), 90 to 99 (center), and from 99 to 109 (right).

Figure 2. The normalized relative backscatter (NRB) signals at 1-minute time resolution are plotted versus the day of year during the ACE-Asia cruise.

Figure 3. Profiles of the NRB signal, aerosol extinction, and aerosol optical depth are shown for April 10, 2001 at 0500 UTC.

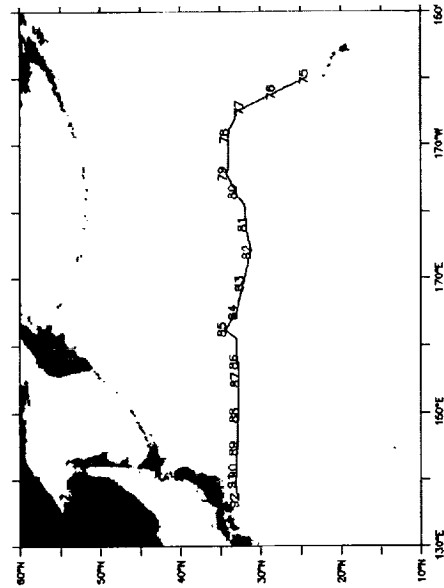
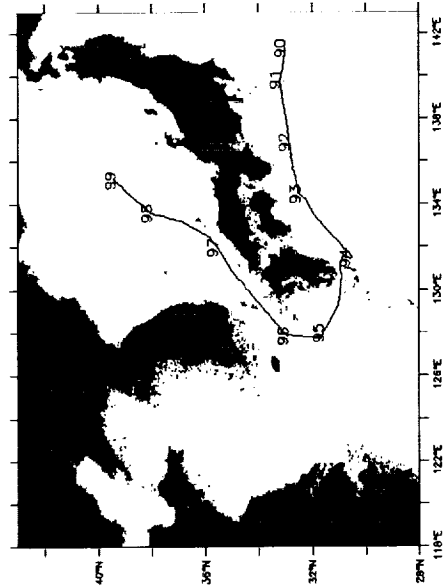
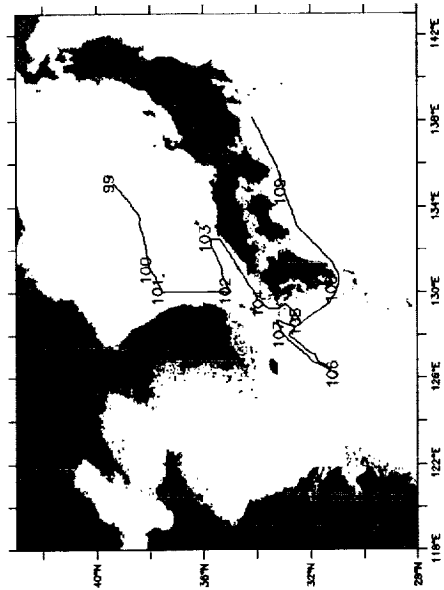


Figure 1

Figure 2

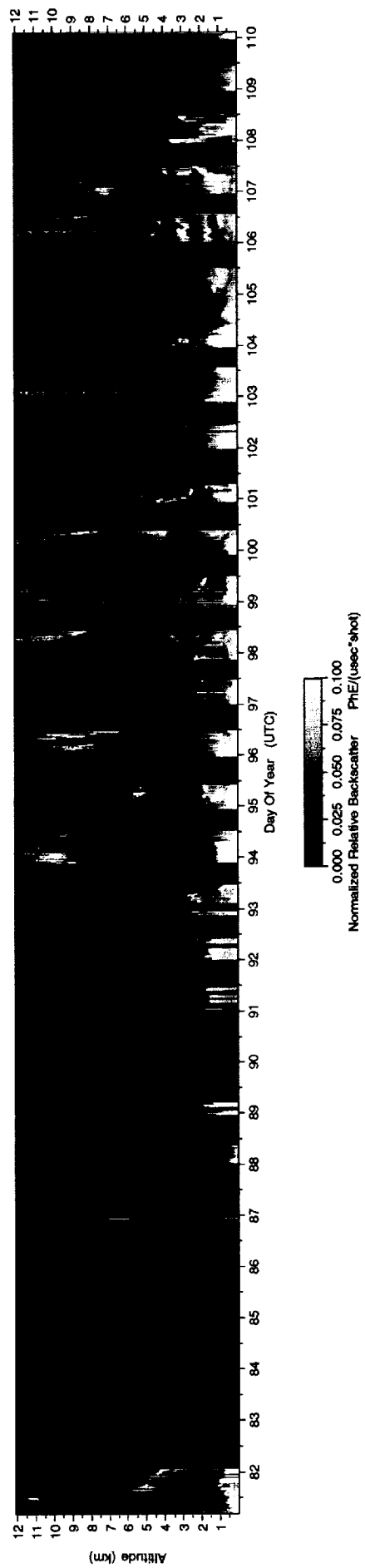
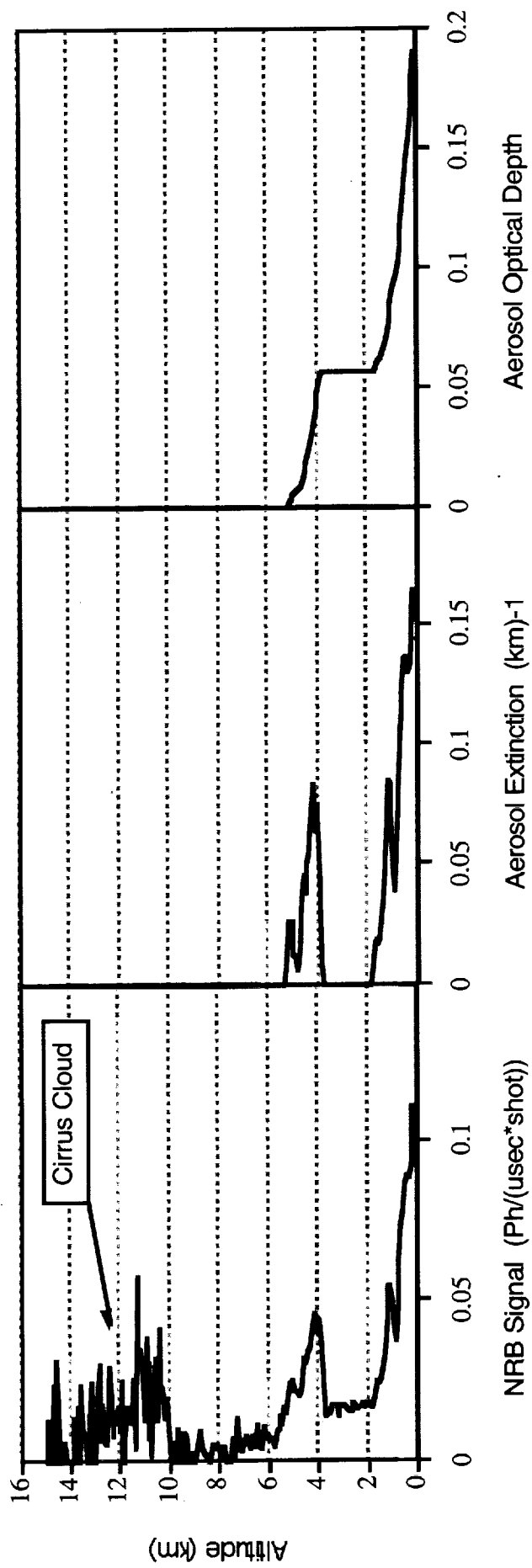


Figure 3



November 15, 2001

## **Measurements of the Vertical Structure of Aerosols and Clouds Over the Ocean Using Micro-pulse LIDAR Systems**

Authors:

Ellsworth J. Welton\*, James D. Spinhirne, James R. Campbell,  
Timothy A. Berkoff, and David Bates

*Submission to the SIMBIOS Project 2001 Annual Report, a NASA Technical Memorandum*

NASA satellite sensors such as SeaWiFS and MODIS are used to measure the amount of sunlight that enters and leaves the upper portion of the world's oceans. Based upon the amount of light emitted at short wavelengths (~400nm), the concentration of chlorophyll can be calculated. This in turn provides an indication of the amount of phytoplankton and algae in the water. This process is referred to as ocean color measurements. Ocean color measurements are used to track the productivity, and "health", of the oceans. This information is used in areas ranging from studies of climate change to improving commercial fishing applications.

In order to view the oceans, the satellites must peer through the atmosphere. Atmospheric constituents such as molecular gases, aerosols (suspended particles), and clouds obscure the satellite's view and can alter the apparent ocean signal. A process termed atmospheric correction is employed to remove the effects of the atmosphere. The atmospheric correction algorithms are based on models of the way the atmospheric constituents interact with sunlight, as well as assumptions of their physical location in the atmosphere and geographically.

In order to verify and improve the correction process, actual measurements of the model's constituent parameters are needed. For the most part, the majority of problem areas have been adequately studied. The remaining areas are being addressed by projects such as the NASA SIMBIOS program. SIMBIOS funds scientists to measure both atmospheric and in-water properties that are needed for ongoing verification of ocean color measurements.

Two areas of interest include the detection of thin cirrus clouds, and the determination of the vertical height of absorbing aerosol layers. The presence of either thin cirrus or aerosols can greatly affect the calculation of ocean color from a satellite, and more information on both is needed for better atmospheric correction.

This report provides an overview of SIMBIOS funded activities to measure both aerosol and cirrus properties using a micro-pulse lidar. Lidars are used to profile the vertical height of aerosol and cloud layers, and can also be used to measure their optical properties. Here we report on the deployment of a lidar onboard a ship during the ACE-Asia 2001 field experiment. The purpose of our involvement was to observe Asian aerosol pollution and dust plumes transported over the northern Pacific Ocean, and to use this information to help improve the calculation of ocean color in this region.

\* Lead Author: Dr. Ellsworth J. Welton  
Goddard Earth Sciences and Technology Center, UMBC  
GSFC Code 912  
welton@virl.gsfc.nasa.gov